Verification Method for SSI Problems with Extended Parameter Ranges

2014 U.S. DOE Natural Phenomena Hazards Meeting

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Introduction

- The U.S. DOE Office of the Chief of Nuclear Safety commissioned a project to Validate and Verify (V&V) SASSI for use within the DOE complex.
- The project developed a large suite of benchmark test cases primarily on the basis of published research.
- Several SSI parameters requiring validation exceed anything provided in literature, thus requiring the development of an alternate verification method.

Background

- The project goal is to ensure SASSI is valid for the range of parameters being implemented with the complex.
- The project is based on a “SSHAC type” of process, composed of:
  - Participatory Peer Review Panel:
    - Prof. Eduardo Kausel, Dr. Wen Tseng, Prof. Aspa Zerva
  - Implementer Team: Carl J. Costantino and Associates
  - Technical Integrator: Dr. James J. Johnson
  - DOE Project Lead: Dr. Brent Gutierrez
  - DOE QA Oversight: Debra Sparkman
  - Stake holder input (workshops)

Background (cont.)

- Phase 1 of the V&V project generated 12 technical calculation packages to develop benchmarks for the following components of SASSI:
  - Green's functions
  - Impedance/compliance of surface and embedded foundations
  - Finite elements
  - Post-processing components (response spectra calculation, transfer function interpolation, etc.)
  - Load formation (seismic and foundation loads)
  - Scattering problem (flexible volume method)
  - Acceptance criteria development

Project Milestones

- The SASSI V&V project is divided into two phases:
  - Phase 1 developed 12 calculation packages to verify parameters of SASSI associated with the UPF and CMRR projects (complete).
    - Several thousand benchmarks were analyzed.
  - Phase 2 will add more generic parameters, and identify a reduced, comprehensive benchmark problem set for the common elements of SASSI.

Extended Parameter Ranges

- Published technical literature provides solutions for foundations with a size and frequency range associated with a maximum dimensionless frequency (a_o) of 10.
  - $a_o = \omega r/V_s$
    - ω is circular frequency
    - *r* is foundation radius
    - V_s is shear wave velocity of the soil profile
- The project required a_o values up to 27 to support current DOE SSI analyses for large foundations with high cutoff frequencies.

Alternate Solution

- Given the high a_o cutoff value needed beyond anything available in published literature, alternate benchmarks were needed to verify foundation compliances SASSI.
- Two alternate solution methodologies were used to develop foundation compliance benchmarks for surface and embedded foundations:
  - CLASSI for rigid, surface foundations
  - The "Green's Function Inversion" (GFI) process
    - Surface and embedded foundations
    - Rigid and flexible foundations

CLASSI

- CLASSI was used to generate rigid foundation compliances for surface foundations with extended parameter ranges.
- CLASSI analyses were performed by Jim Johnson and SGH using a quality assured version of CLASSI.
- In short, the CLASSI methodology involves:
  - Green's function generation from continuum mechanics principles.
  - The Green's functions are integrated over discretized foundation sub-region areas (ie. mesh) to calculate a resultant set of forces and displacements at sub-region centroids.
  - The sub-regions are constrained to the center of the foundation using rigid body constraints.
  - Rigid foundation impedance and scattered motions are computed.

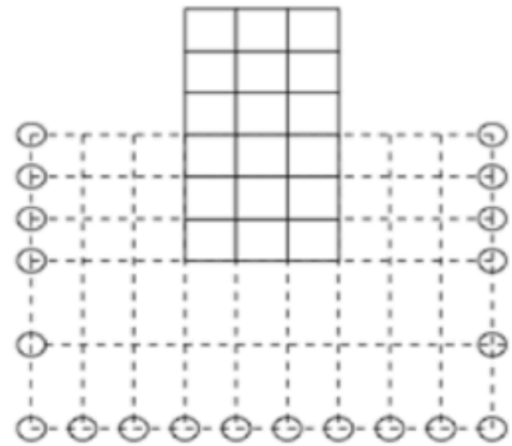
GFI

- GFI is an alternate solution methodology that uses Green’s functions computed from an alternate source (PunchXP) as input.
- PunchXP computes Green’s functions using the Thin-Layer Method
  - Developed by Eduardo Kausel
  - Kausel, E., “The Thin-Layer Method in Seismology and Earthquake Engineering.” In Kausel, E. and Manolis, G., editors, Wave Motion in Earthquake Engineering, pages 193–213. MIT Press.

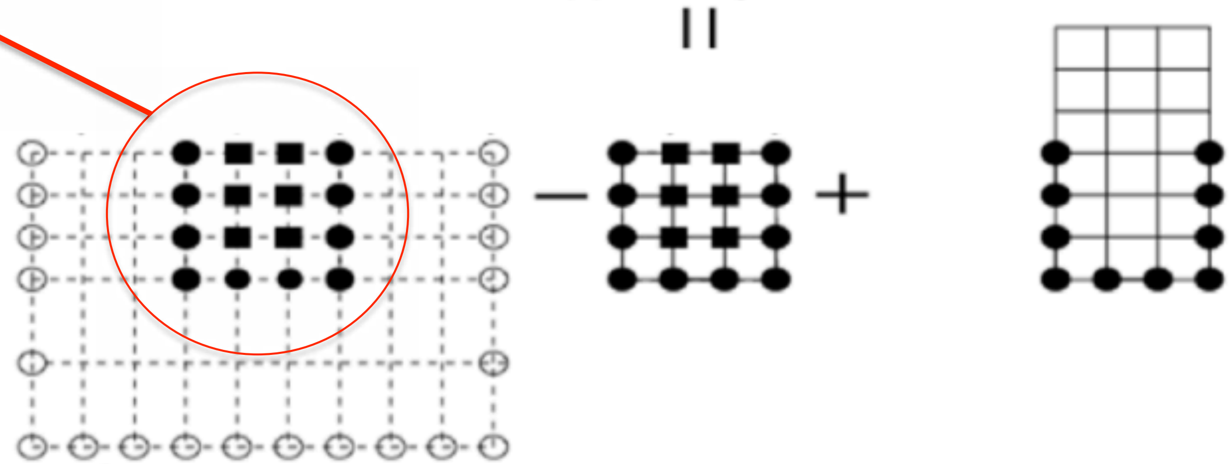
GFI Methodology

- GFI recreates the SASSI sub-structuring approach (direct method only) using Green's functions computed with PunchXP.
- The process is carried out through a combination of PunchXP analyses, Mathematica worksheets and Python scripts.
- This combined process was used in lieu of writing custom code.
  - Writing custom code would invoke significant QA rules beyond the scope of the project.

The impedance values in this phase of the sub-structure process are sourced from PunchXP, rather than those produced by SASSI.



(a) Total SSI system defined by the global dynamic stiffness matrix $[K^*]$, where $[K^*] = [X] - [K_s^*] + [K_p^*]$



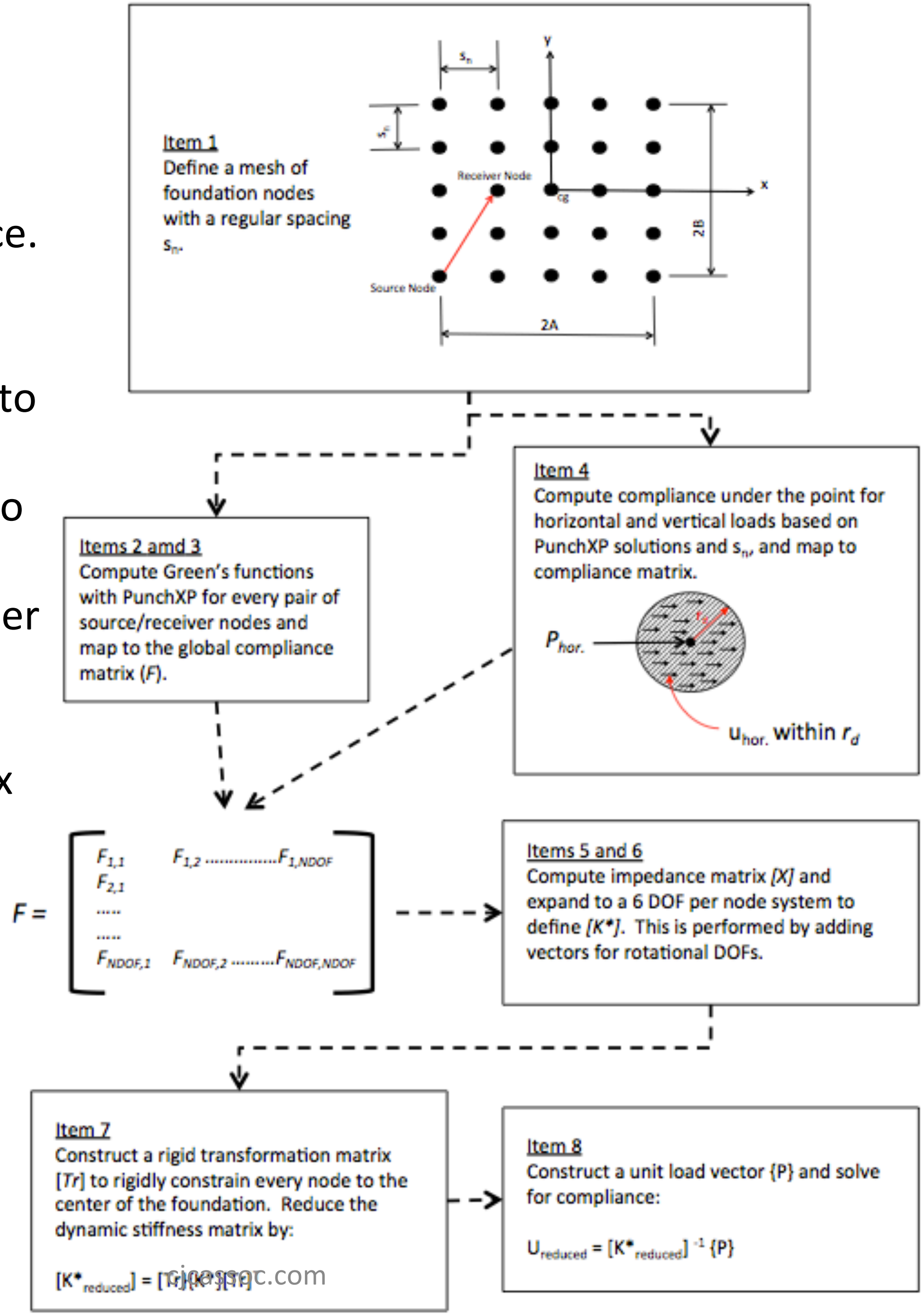
(b) Dynamic soil stiffness at interaction nodes laying within a halfspace, defined by the impedance matrix $[X]$

(c) Finite element stiffness of the excavated soil, $[K_s^*]$

(d) Finite element stiffness of the structure, $[K_p^*]$

The GFI Analysis Process for Rigid, Surface Foundations

1. Generate a mesh defining interaction nodes on a halfspace.
2. Compute Green's functions for each source/receiver pair.
3. Transform Green's functions into compliances in the global coordinate system and map into the compliance matrix, [*F*].
4. Compute disk compliances under the loaded point and map into the global compliance matrix.
5. Compute the impedance matrix by $X = F^{-1}$.
6. Create the global dynamic stiffness matrix and transform to a rigid foundation through rigid constraints.
7. Solve Ax=b for foundation impedance.



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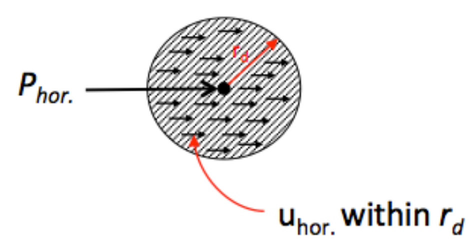
PunchXP Inputs

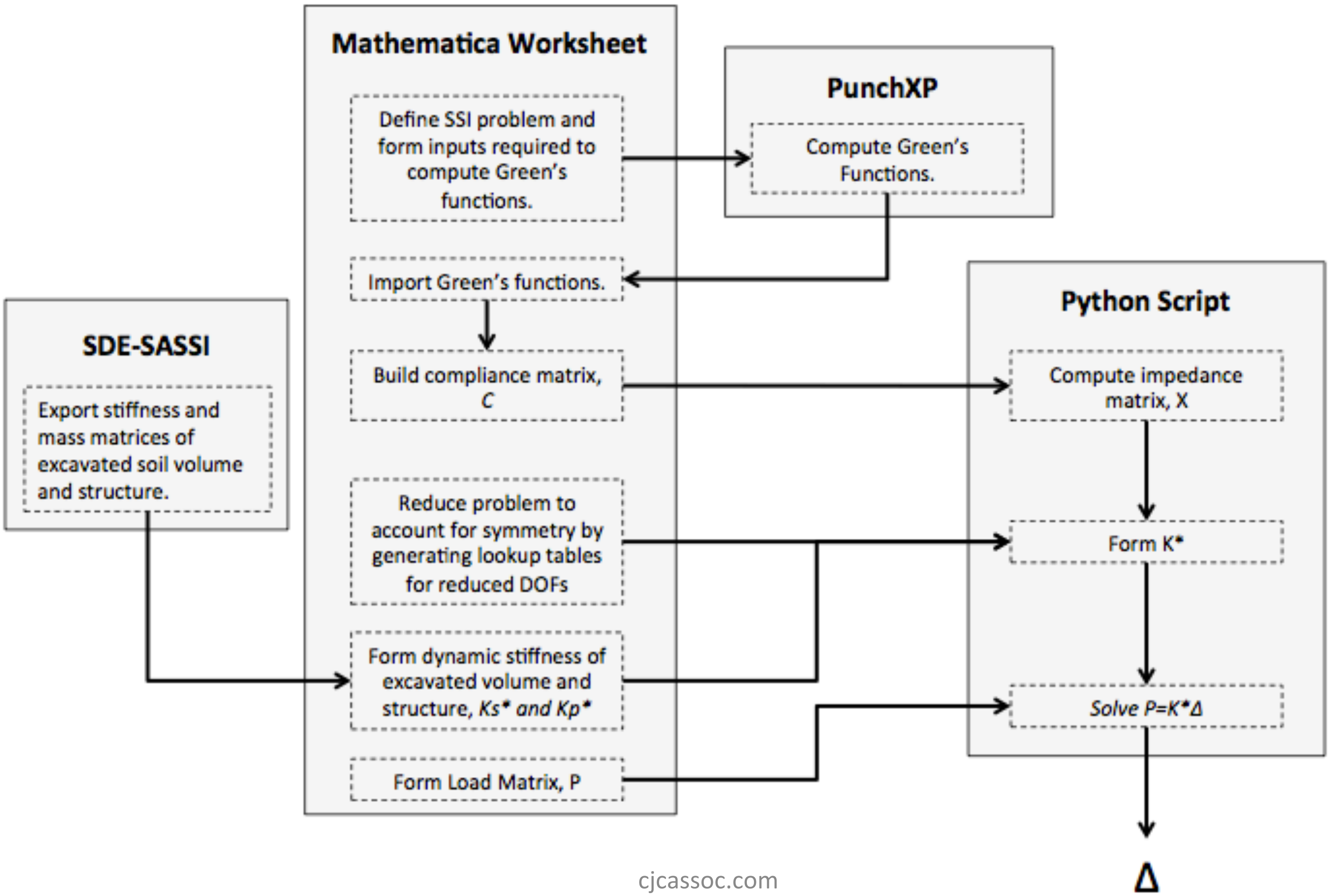
- The PunchXP solution for a point load was used.
  - Values can be used directly for distant source/receiver pairs
- A disk solution was computed for displacements under the loaded point (ie. Δ_{11}) based average computed displacements with a given radius (r_d).
  - r_d is the equivalent radius for the area between adjacent interaction nodes.
- These Green's functions are mapped into the global compliance matrix.



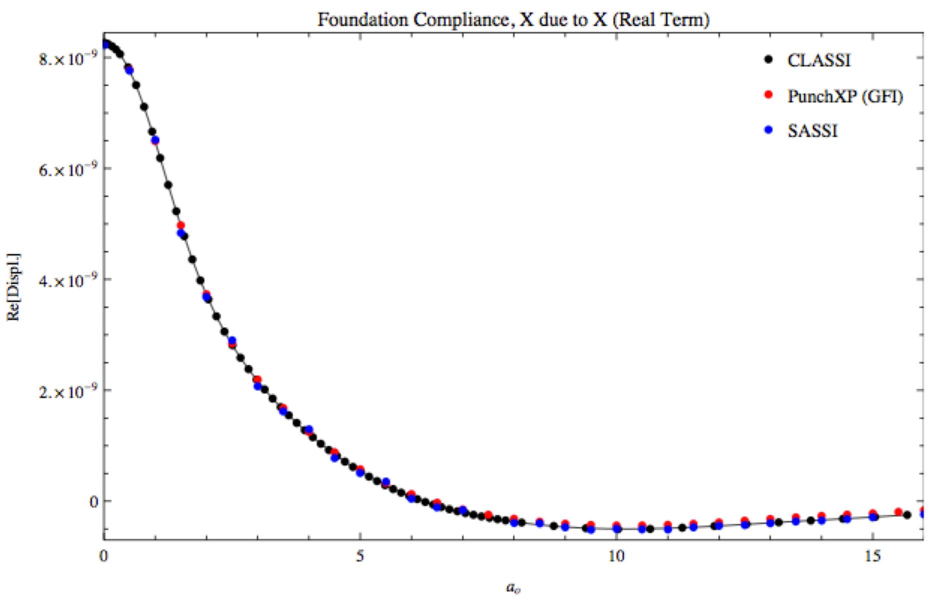
GFI for Embedded Foundations

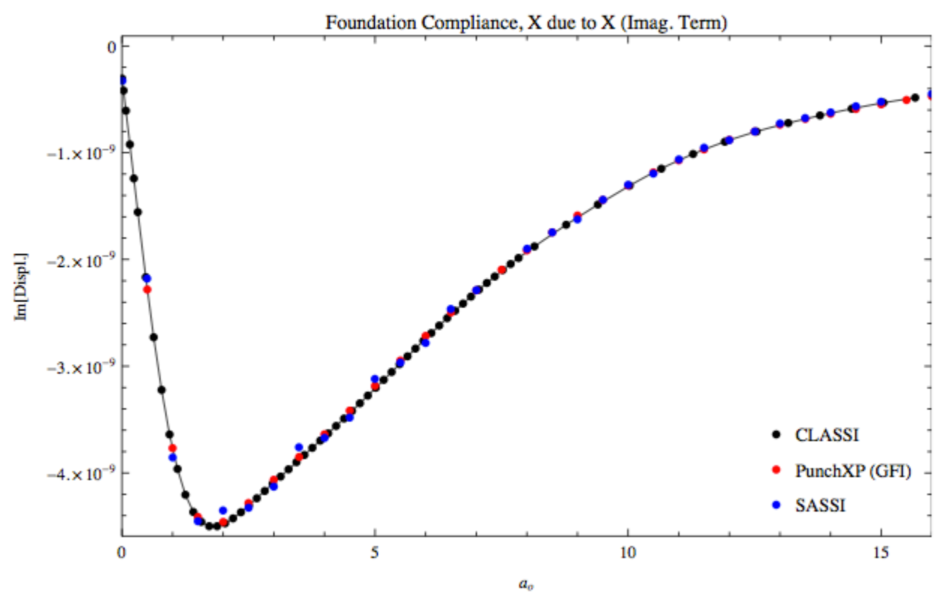
- The GFI analysis for embedded foundations is similar to that of surface foundations.
- In sub-structuring of the SSI problem, the excavated volume is subtracted from the problem.
- A finite element representation of the excavated volume is used (same process as SASSI).

GFI for Embedded Foundations (cont.)

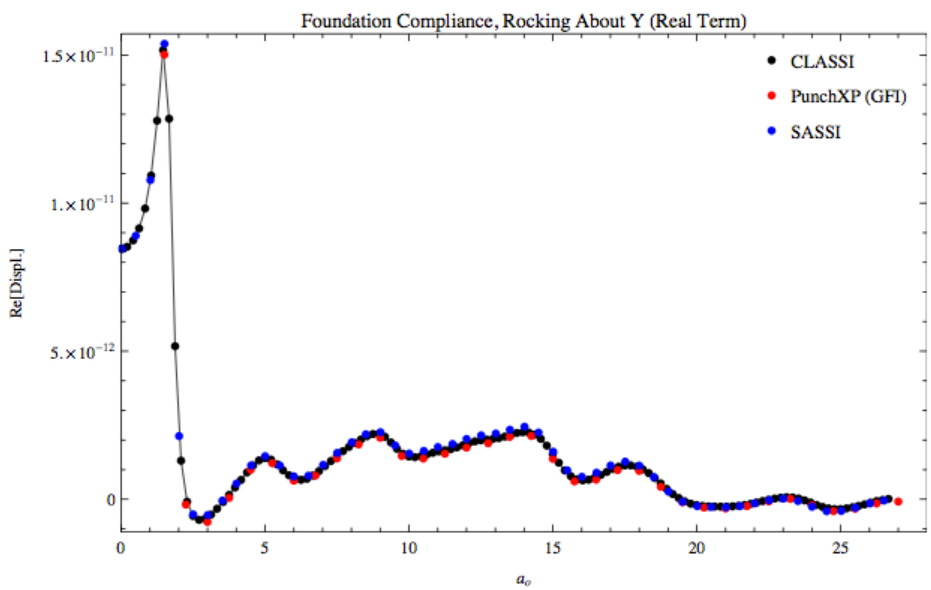


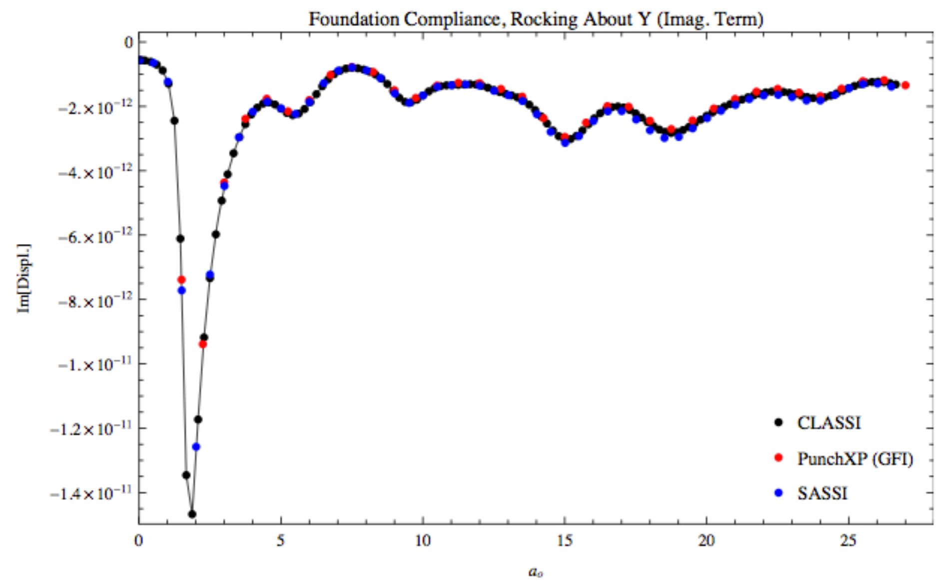
Results Comparison with SDE-SASSI (Translational Foundation Compliance, Surface, Rigid Foundation)



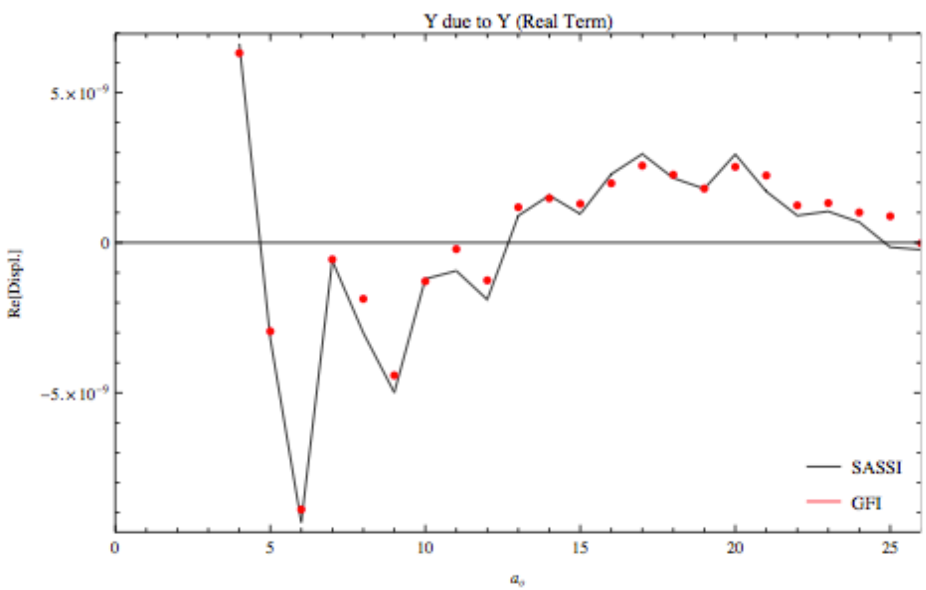


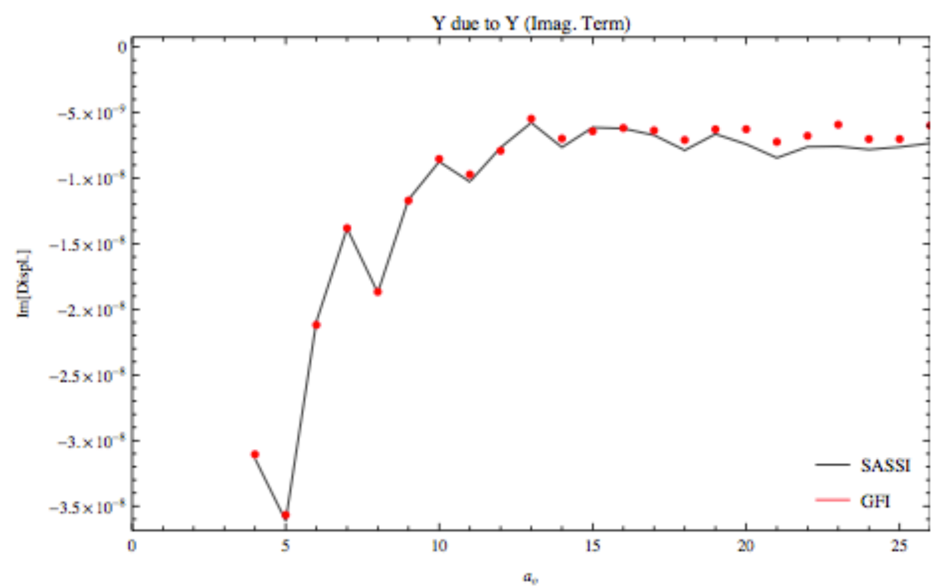
Rocking Foundation Compliance with SDE-SASSI: Surface, Rigid Foundation





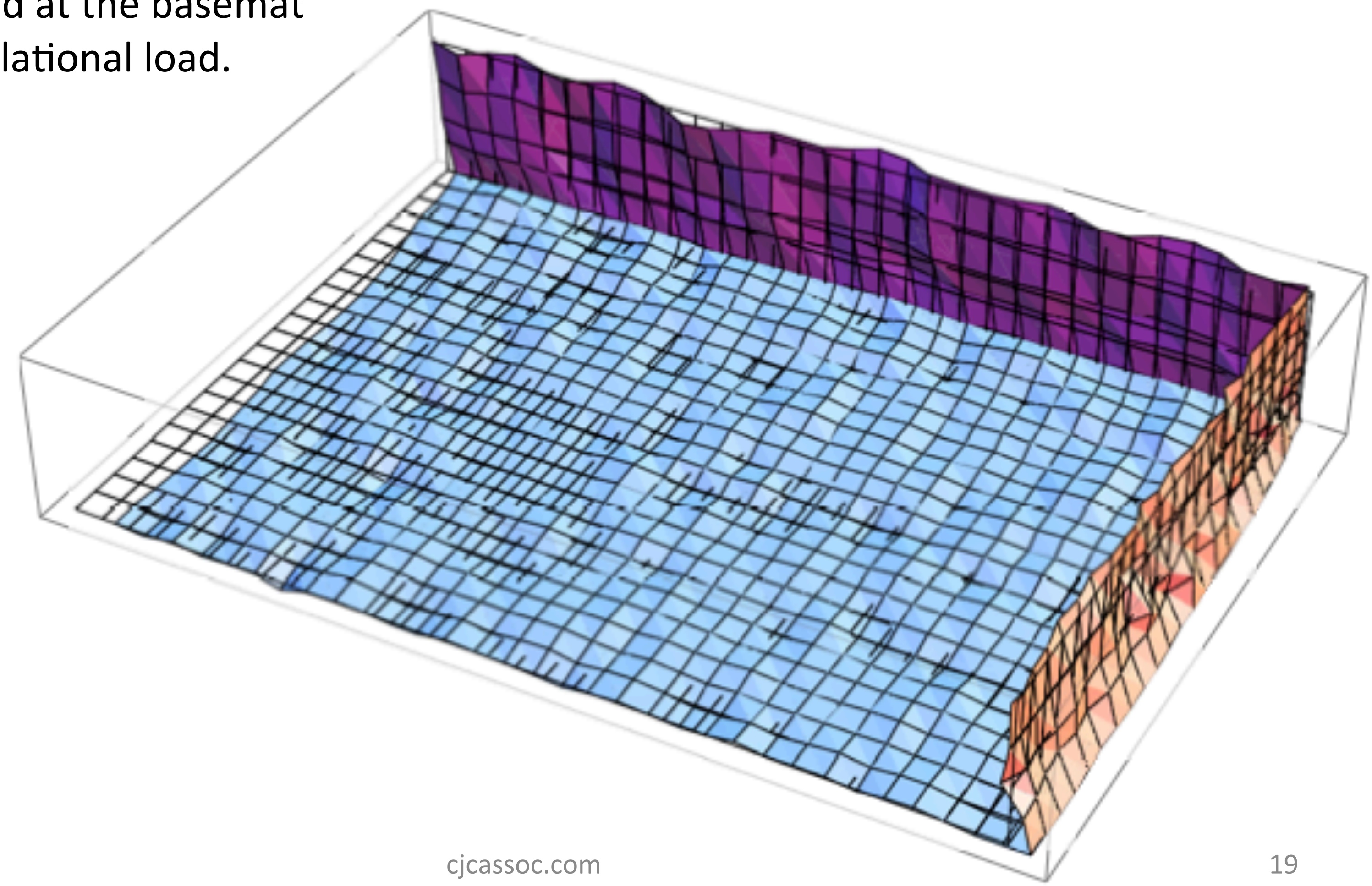
Translational Foundation Compliance with SDE-SASSI: Embedded, Rigid Foundation



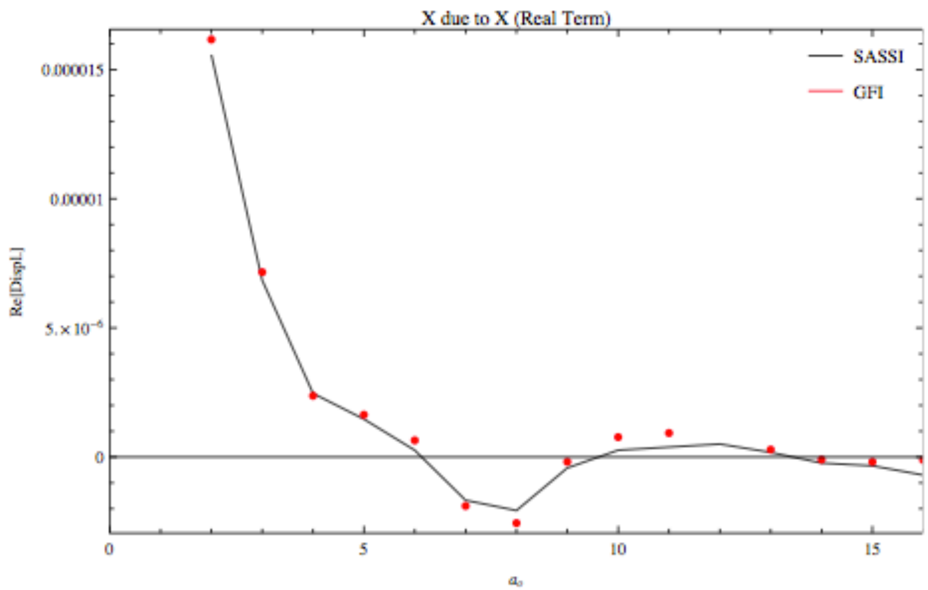


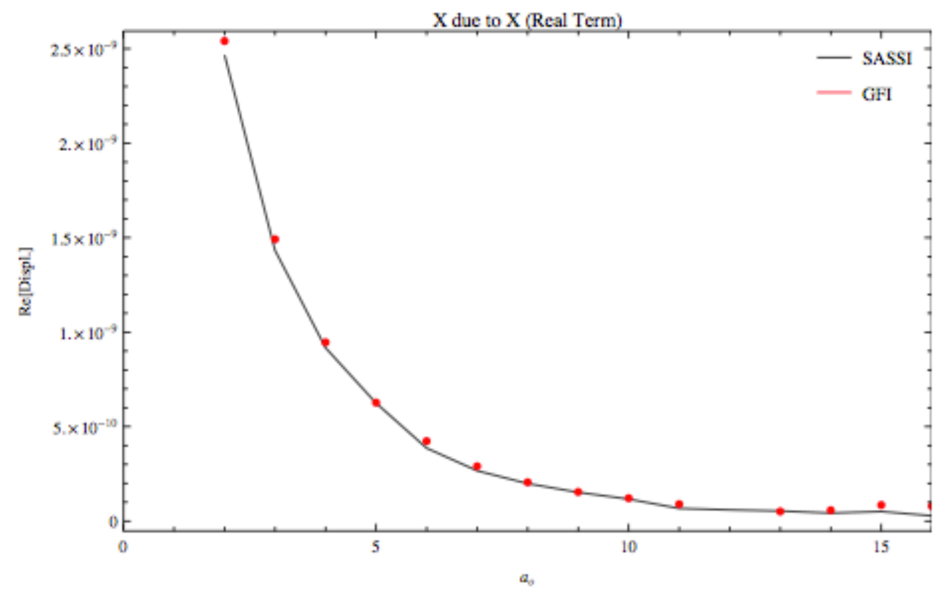
Flexible Foundation Compliance

Displacement profile of a flexible foundation loaded at the basemat level with a translational load.



Translational Foundation Compliance: Embedded, Flexible Foundation





Verification Process

- The Project PRT reviewed the comparisons of the alternate CLASSI and GFI solutions to those generated with SASSI.
- The computed results, along with the wealth of comparisons to published solutions at lower a_o ranges were used to form a judgment that the SSI problem is properly solved by SASSI for extended parameters.

Status of SASSI V&V Project

- Phase 1 calculations have been reviewed and accepted by PRT and Project Technical Integrator.
- DOE HQ anticipates final release of 12 Task packages at end of October 2014.
- Task packages will be made available to stakeholders (contact Dr. Brent Gutierrez).